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SIMULTANEOUS FIVE-WAVELENGTH FILTERING AT 2·2 nm WAVELENGTH SEPARATION USING INTEGRATED-OPTIC ACOUSTO-OPTIC TUNABLE FILTER WITH SUBCARRIER DETECTION

Indexing terms: Optical communications, Integrated optics, Acousto-optical devices and effects, Optical filters

We demonstrate simultaneous, independent, five-wavelength filtering using an integrated-optic acousto-optic tunable filter with a wavelength separation of 2·2 nm. The worst-case power penalty is only 2·2 dB, demonstrating the feasibility of dense multiple-wavelength operation.

Introduction: A recent experiment[1] exploited the unique multiple-wavelength filtering capability[2] of the acousto-optic tunable filter (AOTF) to demonstrate multiple broadband services with only one fixed-wavelength transmitter and receiver per user. In that experiment, the required wavelength separation was 16 nm, owing to the relatively large crosstalk in the bulk-wave AOTF, and only two-wavelength selection was demonstrated because of RF drive power limitations. In this paper, we use an improved integrated-optic AOTF (IAOTF)[3] to demonstrate simultaneous, independent, five-wavelength filtering with a wavelength separation of 2·2 nm and a power penalty of only 2·2 dB. Our experiment indicates that dense multiple-wavelength selection by the IAOTF is possible.

The basic network is a wavelength-independent broadcast star network[1,4] in which every user is assigned a unique wavelength for transmission. Each user can transmit information at baseband or at various microwave subcarrier frequencies.[5] The IAOTF is used to select a combination of optical wavelengths simultaneously, whereas tunable microwave filters are used to select the desired subcarrier channels after optical detection. By assigning wavelengths to users and subcarrier frequencies to individual services, we can achieve multipoint-to-multipoint interconnection and multiple services per user, using only one transmitter and receiver per user.[4] Because of the integration of multiple wavelengths and multiple subcarriers, this approach efficiently utilises the available fibre bandwidth and simultaneously achieves narrow service channel spacings (in the MHz range). The total number of channels in the entire network is $N \times M$, where N is the number of wavelengths and M is the number of subcarrier channels on each wavelength. The maximum number of channels simultaneously available to any user is M.

Experimental demonstration: Fig. 1 shows the experimental setup. Eight DFB lasers, at 1·5330 μm, 1·5378 μm, 1·5400 μm, 1·5422 μm, 1·5444 μm, 1·5466 μm, 1·5521 μm and 1·5546 μm were used as transmitters. The middle five laser transmitters were adjusted to have wavelength separations of 2·2 nm (corresponding to the second null spacing of the IAOTF), and they were modulated by a single 30 Mb/s FSK pseudorandom signal centred on five unique subcarrier frequencies (1·4, 1·1, 1·2, 1·3 and 1·5 GHz, respectively). The optical modulation index for each FSK channel was set to be about 0·8, and the total frequency deviation for each channel was about 30 MHz.

In the optimal use of this network architecture, each laser (or wavelength) can be modulated by a set of subcarriers, and subcarriers of different lasers may overlap in RF frequencies. As long as the desired subcarrier frequencies of the selected wavelengths do not overlap when they are detected, the wavelengths can be selected simultaneously, thus realising multipoint-to-multipoint connection. But for simplicity and for the dense wavelength demonstration here, we did not put overlapping subcarriers on the five wavelengths.

The modulated laser signals were polarisation-controlled and combined by several single-mode broadband (1·3–1·6 μm) star couplers. The output beam was collimated, passed through a polarising beam splitter, and then into the IAOTF.

The IAOTF was an X-cut $Ti:LiNbO_3$ single-mode channel waveguide (1·3–1·56 μm) fabricated with an interdigital SAW transducer. It had a filter bandwidth (FWHM) of 1·0 nm.[3] The maximum conversion efficiency was ≥98% at an RF drive power of 500 mW (~175 MHz). Since the transducer could tolerate ~1 W of power, we chose to select five wavelengths,

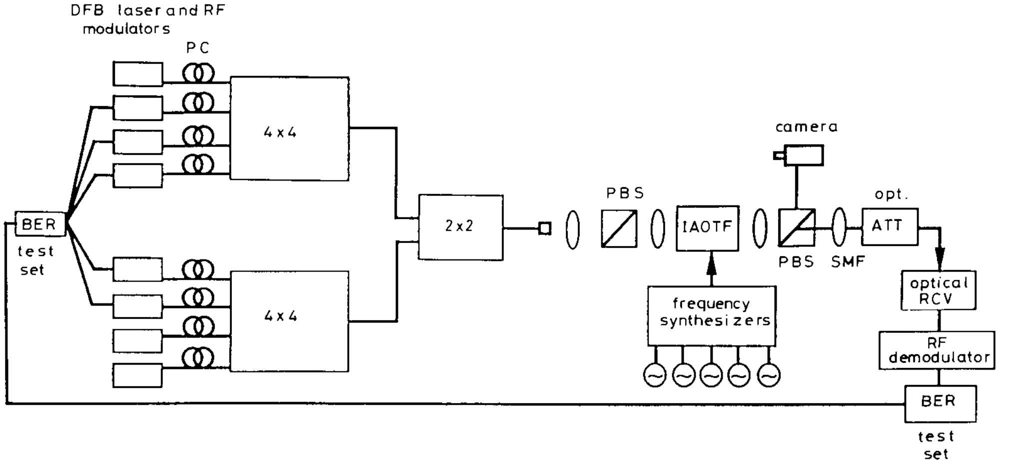

Fig. 1 *Experimental set-up*

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with each wavelength driven by 180 mW of RF power, resulting in a conversion efficiency of ~70% per wavelength selected. Independent CW signals generated from five frequency synthesisers were used to select the five independent optical wavelengths simultaneously.

The filtered optical beam was then coupled back into a single-mode fibre for detection by a commercial transimpedance receiver (optimised at 2·4 Gb/s baseband). The input and output optical spectra are shown in Fig. 2. The total fibre-to-fibre (single-mode) insertion loss of the IAOTF, including the 2 dB insertion loss of the bulk polarisers, was 8·7 dB.

Fig. 3 shows the worse-case power penalty, the eye pattern at a BER of 10^{-9}, and the RF spectrum of the detector output which contains all five subcarrier channels. The worse case power penalty corresponds to the 1·2 GHz subcarrier channel of the 1·5422 μm transmitter (the middle of the five selected wavelengths), and was measured to be 2·2 dB. About 1 dB of the penalty was accounted for by the coherent heterodyne effect[1,6] that arose from the five RF driving frequencies interacting with a single optical wave in the IAOTF. The rest of the penalty was probably due to the imperfections in the RF synthesiser chain that caused further coherent heterodyne degradation.

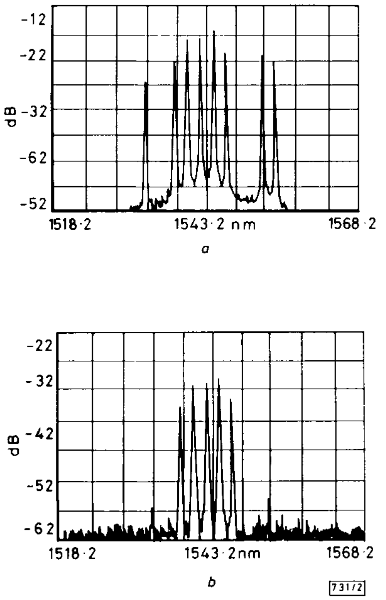

Fig. 2

a Input optical spectrum
b Output optical spectrum

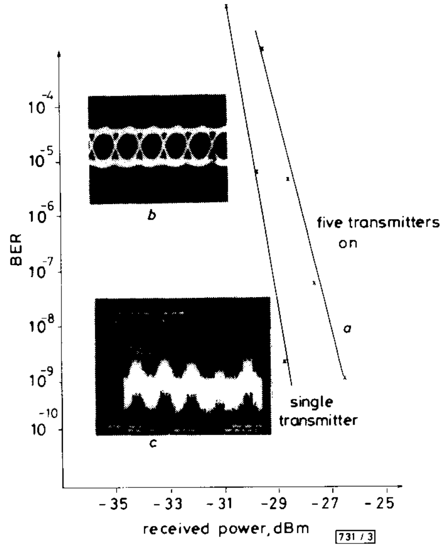

Fig. 3

a Worst case power penalty
b Eye pattern at BER = 10^{-9}
c RF spectrum of detector output

Conclusion: We have demonstrated simultaneous, independent, five-wavelength filtering using an integrated-optic acousto-optic tunable filter with a wavelength separation of 2·2 nm. The worst-case power penalty due to the coherent heterodyne effect is less than 2·2 dB at this wavelength separation, demonstrating the feasibility of dense multiple-wavelength operation.

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HIGH-EFFICIENCY CW OPERATION OF MOCVD-GROWN GaAs/AlGaAs VERTICAL-CAVITY LASERS WITH RESONANT PERIODIC GAIN

Indexing terms: Semiconductor lasers, Refractive index profiles, Vapour deposition

A GaAs/AlGaAs vertical-cavity surface-emitting laser with resonant periodic gain has been grown by metal-organic chemical vapour deposition. The as-grown structure exhibits an optically pumped CW threshold below 15 mW at 300 K and a single-ended power efficiency up to 45%. Fundamental Gaussian and higher-order modes are observed with spectral widths (FWHM) as low as 0·27 Å.

Introduction: Applications in optical communications, computing, solid-state laser pumping and high-power 2D arrays will benefit from the development of semiconductor lasers which emit normal to the wafer surface. Of the currently available approaches (grating coupling, turning mirrors and vertical cavities), the vertical cavity surface emitting laser (VCSEL)[1] places the most stringent demands on material quality. However, the benefits gained from VCSELs include